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Size-class prevalence of bulbous and perennial herbs sold in the Johannesburg medicinal plant markets between 1995 and 2001

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Abstract

Commercial harvesting of perennial herbs and geophytes for the medicinal plant trade has resulted in significant levels of resource depletion for several of the species concerned. One way to quantify the impacts is to estimate the number of bulbs harvested annually. Using records of bulb diameters sold in the Witwatersrand traditional medicinal plant markets between 1995 and 2001, the diameter size-classes most prevalent in the markets were ascertained. Thereafter, the number of 'individual equivalents' was estimated, i.e. the number of individual bulbs harvested annually equivalent in size to the mean diameter of the bulbs known to be traded. The estimates obtained include scenarios for bulbs of different diameters (reflecting the modal frequencies). The results showed there to be a significant decrease in the modal diameter of *Eucomis autumnalis* bulbs prevalent in the markets between 1995 and 2001 from 8 cm to 4 cm respectively. The diameters of *Drimia* spp. bulbs, the most popular species in the Witwatersrand markets, were also decreasing, but the differences were not significant by 2001. Scenarios for the number of *Drimia* spp. bulbs estimated to be sold to the Witwatersrand *TM* shops in 1995 ranged from 270 618 to 552 022 bulbs per annum. Gatherers are harvesting smaller and smaller bulbs over time and this is not sustainable at current rates, especially if more smaller bulbs are sold. It is thus clear that cultivation is necessary to mitigate the effects of further exploitation.

Keywords: Bulbs; Harvesting impacts; Medicinal plants; Perennial herbs; Resource use

1. Introduction

Commercial collecting for the medicinal plant trade is a major cause of resource depletion (Cunningham, 1988), the impact of which is partly dependent on the plant part removed and the level of harvesting effort and gatherer 'efficiency'. Plant populations can be driven to extinction if increases in harvesting effort chase an ever-diminishing yield (Begon et al., 1986). Damage assessments to tree populations have been based on the presence of debarked trunks (e.g. Botha et al., 2004; Geldenhuys, 2004; Twine, 2004), but for bulbous plants often little sign remains of their former presence in a locality (Cunningham, 1988). Hence, estimates on the extent of resource depletion based on population off-take are difficult to evaluate, especially if there is a paucity of data on plant population sizes and structures as well.

Whole plants, roots and bulbs account for ≈ 50% of the > 500 species and 48% of the volume of plants sold in the Faraday market for traditional medicine in Johannesburg (Williams, 2003). While data on the estimated volume of plants purchased by the traders informs the magnitude of resource depletion, the sustainability of harvesting and the scale of cultivation required to substitute wild-collected stocks would benefit from knowing how many individual plants are extracted. The intention of this paper was to quantify the negative impact of commercial harvesting by investigating and estimating the number of plants harvested annually using the concept of 'individual equivalents'.

'*Individual Equivalents*' is a concept conceived specifically to estimate the number of individual plants harvested, and the potential condition of the resource base, directly from trade and market information (Williams et al., in press). In the case of trees, estimates of the number of individual debarked stems were derived from the bark quantity traded and the number of individual trees that had a stem diameter and bark thickness equivalent to similarly sized individuals for which harvestable bark mass per stem was determined (Williams et al., in press). In this paper, estimates of the number of individual geophytes harvested were based on the number of individuals equivalent in

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Table 1
Perennial herbs investigated in this study

Species	Family	Common name	Underground organ-type
Drimia spp.	Hyacinthaceae	Skanama, isiKlenama	Bulb
Eucomis autumnalis	Hyacinthaceae	uMathunga	Bulb
Merwilla plumbea	Hyacinthaceae	inGuduza	Bulb
Hypoxis spp.	Hypoxidaceae	iLabatheka, iNkomfe	Rhizomatous tuber/corm
Scabiosa columbaria	Dipsacaceae	iBheka	Persistent woody rootstock
Dianthus mooiensis	Caryophyllaceae	Tjanibeswe	Persistent woody rootstock

size (i.e. bulb diameter) to the plants for which the number of individual bulbs per bag was determined. For example, if one 50-kg size bag contained ≈ 138 bulbs, each 8 cm in diameter, and ten 50-kg bags were known to be sold over a period of time, then the *equivalent* number of *individual* 8 cm bulbs estimated to be harvested is 1380 'individual equivalents'. If, however, a bag contained ≈ 282 bulbs, each 6 cm in diameter, then the number of 'individual equivalents' would be 2820 bulbs.

Trade data for six selected perennial herbs were acquired during three surveys of traditional medicine vendors in Johannesburg between 1995 and 2001 (Williams, n.d.). From the bulb diameter and mass records for four bulbous geophytes, the relationship between bulb diameter and mass was correlated, the most prevalent size-classes sold by vendors was established, the change in diameter size-classes over a six-year period was investigated, and the number of 'individual equivalent' bulbs extracted annually from the source populations was estimated.

2. Methods

2.1. Species investigated

A perennial herb is defined here as a vascular plant whose life span extends over more than 2 years, that does not produce persistent above-ground woody tissue but may have under- or partially above-ground storage organs (such as bulbs, corms, rhizomes or rootstock) (Van Wyk and Malan, 1988; Von Ahlefelt et al., 2003). Of the perennial herbs investigated, three species are bulbous, one is rhizomatous/cormous and two species have woody rootstocks with long, persistent, carrot-like roots (Table 1) (Fig. 1).

Drimia spp. are the most popular bulbs, and refer to at least two species traded in the markets by the common names *skanama* or *isiKlenama*. In Johannesburg, at least 60% of the *Drimia* spp. bulbs are the reddish-coloured *D. elata* Jacq. The remaining 40% are *D. altissima* (L.f.) Ker Gawl. (Also known as *white skanama*). *Eucomis autumnalis* (Mill.) Chitt. and *Merwilla plumbea* (Lindl.) Speta (formerly *Scilla natalensis* Planch.), known as *uMathunga* and *inGuduza* respectively, are also in high demand. *Hypoxis* spp. refers to *H. colchicifolia* Bak. and *H. hemerocallidea* Fisch. and Mey., known as iLabatheka or iNkomfe. The species investigated that have persistent woody rootstocks are *Scabiosa columbaria* L. (iBheka)

Fig. 1. The species investigated: (a) *Hypoxis* spp. corms; (b) *Merwilla plumbea* bulbs; (c) *Scabiosa columbaria* roots; (d) *Dianthus mooiensis* roots; (e) *Eucomis autumnalis* bulbs; (f) *Drimia elata* bulbs.

and *Dianthus mooiensis* F.N. Williams (Tjanibeswe). In KwaZulu-Natal, a similar species to *D. mooiensis*, namely *Dianthus zeyheri* Sond. (iNingizimu), tends to be used. Depending on the size, bulbs are sold in handfuls equivalent to 6±2.3 bulbs (Williams, 2003) whereas *S. columbaria* and *D. mooiensis* are sold in bundles consisting of ≈ 25 individual plants.

2.2. Market surveys and quantitative resource inventories

The prevalence of the bulbous and perennial herbs of varying sizes sold by medicinal plant vendors was determined from three studies conducted between 1995 and 2001. Between April and October 1995, the six species were measured in 27 traditional medicine shops on the Witwatersrand. The Witwatersrand is an extensively urbanised area within the province of Gauteng, with Johannesburg located approximately at the centre of this region. Quantities of the species equivalent in volume to a typical retail sale to a customer were weighed and measured. Bulb diameter was measured using a Vernier calliper across the widest point along the horizontal axis. The bulbs were weighed using a portable digital scale accurate to 5 g. The length of the woody rootstock was measured from the leaf base to root tip. Additionally, traders were asked how many bags per annum of each species they purchased. In a second study between July and September 1995, plant samples were purchased on ten visits to the Faraday market. Faraday is a large, informal wholesale and retail street market in Johannesburg with currently more than 200 vendors. The plants were weighed and measured in the same way as the shop survey, but no data were collected on the annual volume sold.

In January 2001, an extensive semi-quantitative study of Faraday was conducted on behalf of the provincial Directorate for Nature Conservation within the Department of Agriculture, Conservation and Environment in Gauteng (Williams, 2003,

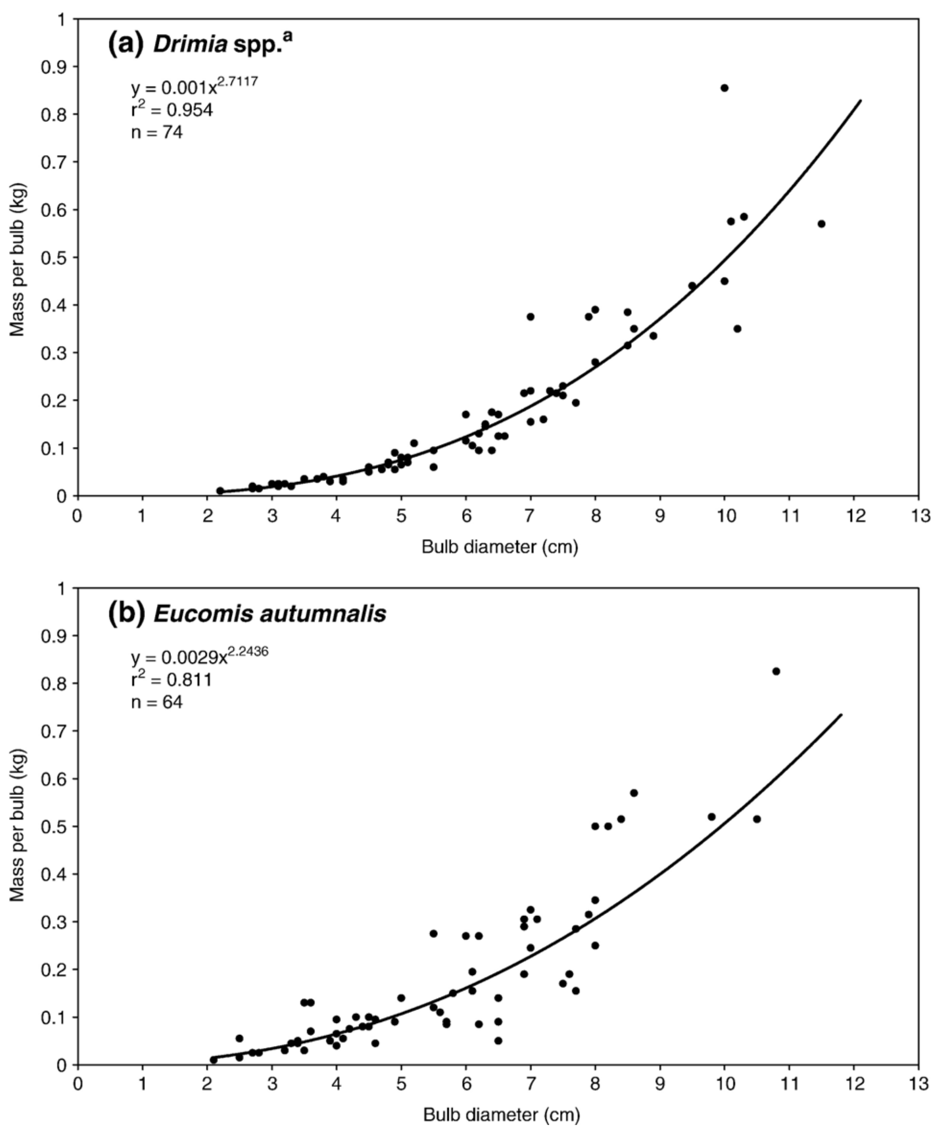

Fig. 2. Regression relationships between bulb/corm mass and diameter, for data collected in the traditional medicine shops and Faraday market in 1995, for (a) *Drimia* spp., (b) *E. autumnalis*, (c) *M. plumbea* and (d) *Hypoxis* spp. The diameter was measured as the widest point along the horizontal axis. [a]*Drimia* spp: *Drimia elata* and *D. altissima* (see text). [b]*Hypoxis* spp: *H. colchicifolia* or *H. hemerocallidea*.

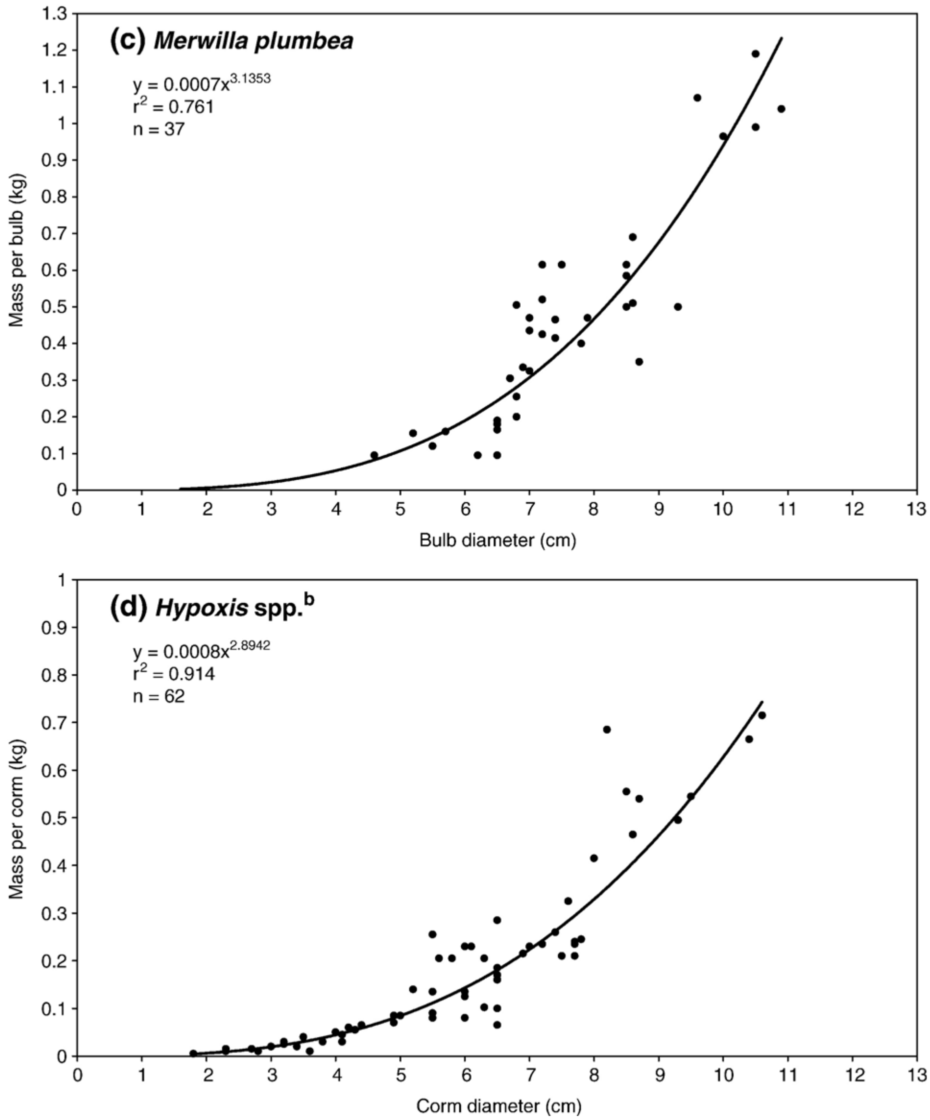

Fig. 2 (*continued*).

2004). One hundred traders were interviewed and a quantitative inventory of every plant sold by each trader was compiled, including the quantity of each species present in the market and the estimated size of the plant part. Given time constraints and the number of species in the market (>500) (Williams, 2003), it was not practical to accurately weigh and measure each individual bulb. Instead, bulbs that were generally representative of the size of the stock on sale were selected and bulb diameter was visually estimated and categorised into 1 cm diameter size-classes. None of the plants were weighed, and the length of woody rootstocks was not measured. Traders were also asked how often they purchased plant stock equivalent in volume to a 50-kg maize bag.

2.3. Estimating the annual quantity of bulbs and rootstocks traded

Medicinal plants are usually transported to the markets in 50-kg size bags. The actual mass of the contents of a bag depends on the plant part (e.g. bulbs or leaves) and its density and moisture content. The number of individuals in any bag depends on the size dimensions of the plant part. The annual quantity of plants purchased by the shops in 1995 was estimated by determining the mean number of bags purchased per trader per annum (bags a^{-1}), and then multiplying this by the proportion of shops selling the species. The annual quantity purchased by the traders in Faraday in 2001 was calculated slightly differently. The frequency with which the traders purchased one bag of the species was determined, and then the number of bags that would have been bought annually was calculated depending on the proportion of traders who sold the species.

2.4. Calculating the number of 'Individual Equivalents'

Bulbs range in size in the markets, and the bulb diameters used to calculate the numbers of 'Individual Equivalent' bulbs harvested annually were standardized to be equivalent to the modal bulb diameters sold by vendors in a specific year. From raw data for seven bulbous listed in Cunningham (1988, Table 5, page 31) on the mean number of bulbs of a mean specified size contained in a 50-kg bag, regression analysis was used to plot the relationship between bulb size and the number of bulbs per bag. Thereafter, the number of bulbs of a standardized size harvested annually was estimated from the number of bulbs per bag and the number of bags purchased per annum.

Bulb populations may suffer varying degrees of damage depending on the popularity of the species, the intensity of harvesting and the size and/or maturity of the bulbs harvested from wild populations. Estimates of the number of bulbs harvested can therefore be adjusted to reflect scenarios for the different bulb sizes removed, e.g. 6–8 cm, and the number of Individual Equivalents would vary accordingly. Estimates for the number of individuals harvested for species with woody rootstocks (namely *D. mooiensis* and *S. columbaria*) were based on the mean number of individual plants per bundle and Cunningham's (1988) estimate of 200 bundles of plants per 50-kg bag.

2.5. Statistical analyses

Regression analyses were used to describe the relationship between bulb diameter and mass for bulbs sold by the traders in 1995. One-way ANOVAs were computed to test the differences in the mean bulb sizes sold in the TM shops in 1995 (S 1995) and the Faraday market in 1995 and 2001 (F 1995 and F 2001 respectively). The significance between the group means for S 1995, F 1995 and F 2001 was determined using the post hoc Tukey HSD multiple comparison test for unequal *N*. Excel and Statistica 6 were used for the statistical analyses.

3. Results

3.1. The relationship between bulb mass and diameter

The strongest regression relationships between bulb mass and diameter were for *Drimia* spp. and *Hypoxis* spp. ($r^2 = 0.954$ and 0.914 respectively) (Fig. 2a and d). *Drimia* has somewhat fleshy bulb scales, often tipped with the remains of dead leaves,

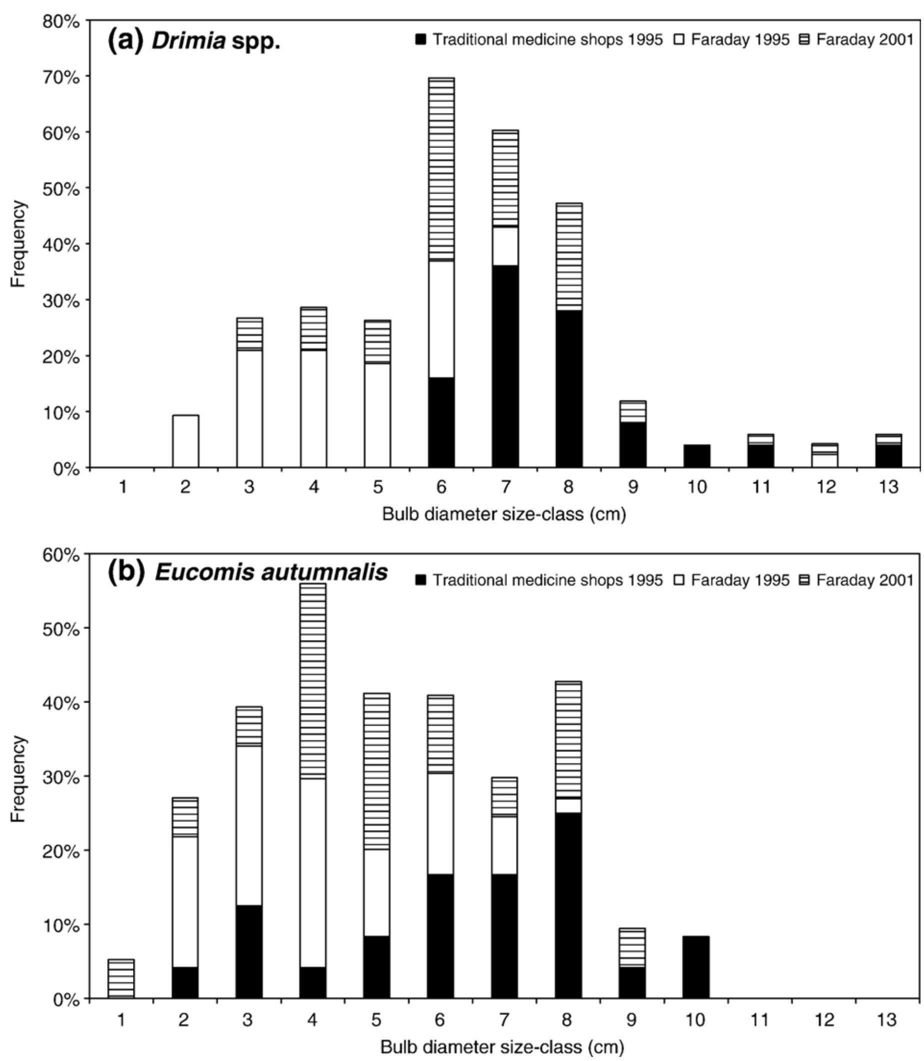

Fig. 3. Bulb/corm size availability in the traditional medicine shops and Faraday Street market between 1995 and 2001 for (a) *Drimia* spp., (b) *E. autumnalis*, (c) *M. plumbea* and (d) *Hypoxis* spp.

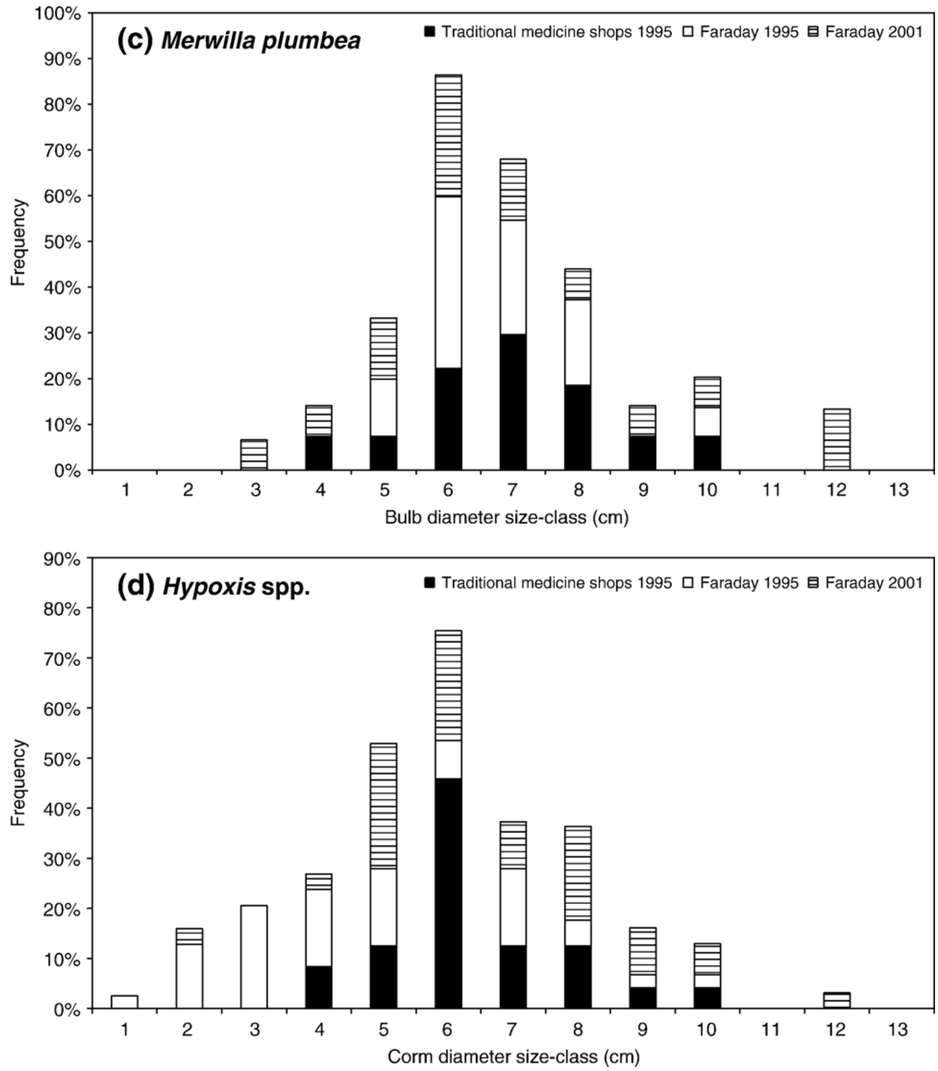

Fig. 3 (*continued*).

and *Hypoxis* has a swollen corm. The weaker regression relationships were for *E. autumnalis* and *M. plumbea* — species with dry, papery and flaky outer bulb scales (r^2=0.811 and 0.761 respectively) (Fig. 2b and c).

3.2. Mean size and mass of the species sold by traders

Drimia spp. bulbs sold in the shops in 1995 and the Faraday market in 2001 were mostly 6–8 cm in diameter, with the modes being 7 cm and 6 cm respectively (Fig. 3a). However, bulbs bought in Faraday in 1995 were mostly 3–6 cm in diameter. *Drimia* bulbs <6 cm were not recorded during the 1995 shop survey, but they were recorded in Faraday in 1995 and 2001. *E. autumnalis* bulbs were mostly 6–8 cm in the shops in 1995, compared to 4–6 cm in Faraday in 2001 (Fig. 3b). The modal diameters also declined from 8 cm to 4 cm. However, *E. autumnalis* bulbs bought from Faraday in 1995 were mainly 2–4 cm. *M. plumbea* bulbs were usually large and 6–8 cm in 1995 and 5–7 cm in 2001 (Fig. 3c). The modal diameter declined from 7 cm to 6 cm respectively and there were no incidences of bulbs <3 cm, as was the case with the other species. The corms of *Hypoxis* spp. sold in the shops in 1995 and the Faraday market were usually 5–8 cm in diameter and the modal sizes were 6 cm and 5 cm respectively (Fig. 3d). *Hypoxis* corms bought from Faraday in 1995 were 3–5 cm, and the mode was 3 cm.

Overall, there was a general decline in bulb diameter when comparing samples from the shops in 1995 and Faraday in 2001 (Fig. 3), but bulbs purchased from Faraday in 1995 were smaller than the bulbs recorded in Faraday in 2001 (except for *M. plumbea*) (Figs. 3 and 4). One-way ANOVAs comparing the mean bulb sizes in the shops and Faraday in 1995 (S 1995 and F 1995 respectively), and in Faraday in 2001 (F 2001) indicated that the mean diameters of *Drimia* spp., *E. autumnalis* and *Hypoxis* spp. were significantly different at $P<0.05$ (Fig. 4). However, the mean diameters of *M. plumbea* bulbs were not significantly different.

The Tukey HSD test revealed that *Drimia* bulbs bought from Faraday in 1995 (F 1995) were significantly smaller than the bulbs sold in Faraday in 2001 (F 2001) and in the shops in 1995

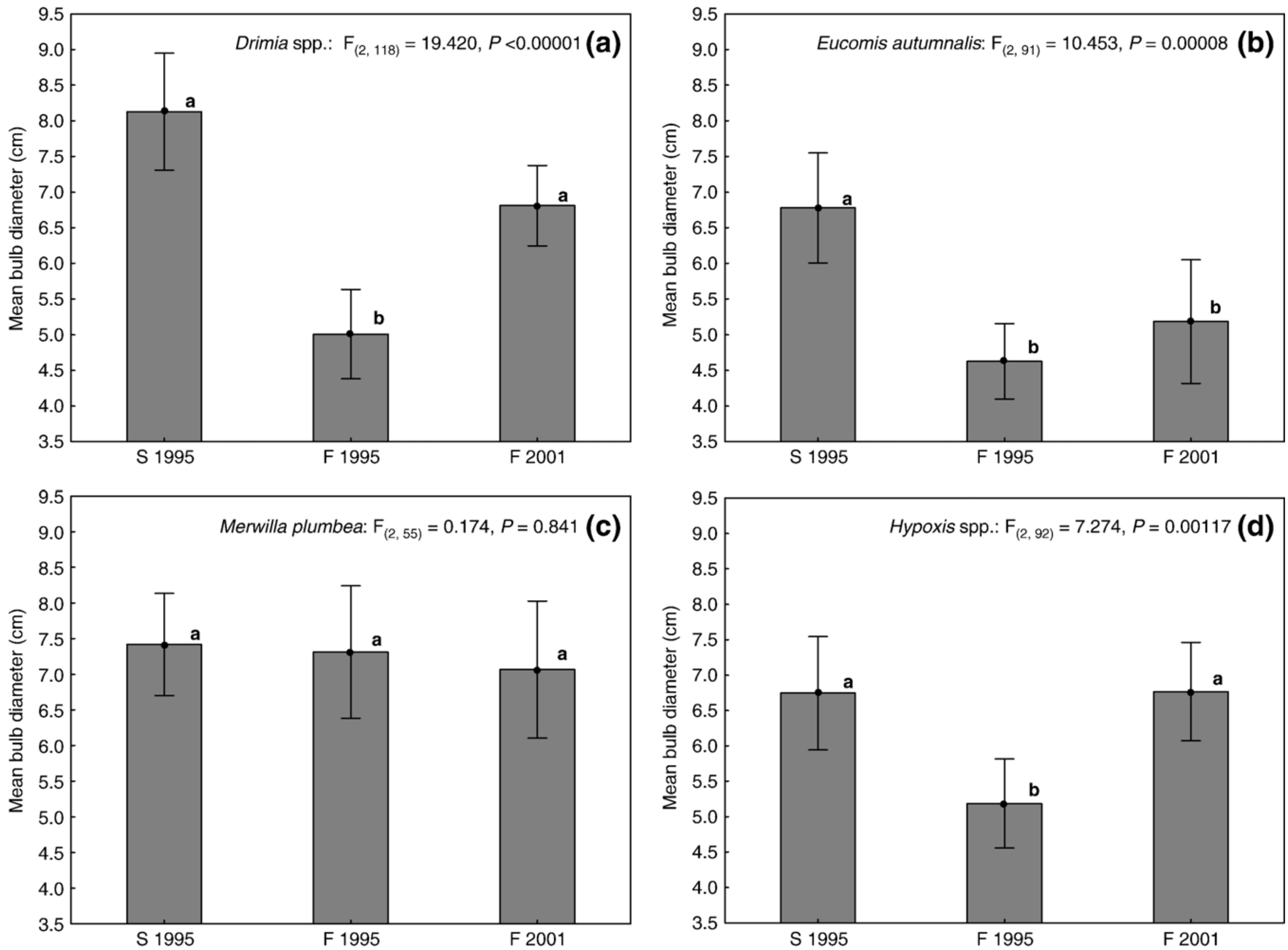

Fig. 4. Mean (±95% confidence interval) bulb diameters for species sold in the Witwatersrand traditional medicine shops in 1995 (S 1995) and the Faraday market in 1995 and 2001 (F 1995 and F 2001 respectively). Results of one-way ANOVAs are also included. Means with the same letters are not significantly different (Tukey HSD, $P<0.05$).

(S 1995) ($P=0.0004$ and 0.0001 respectively) (Fig. 4). However, *Drimia* bulbs sold in the shops in 1995 were not significantly bigger than those recorded in Faraday in 2001 were ($P=0.068$). The results for *Hypoxis* spp. were similar to *Drimia* spp., with bulbs sold in the shops and Faraday in 1995 and 2001 being significantly larger than bulbs bought in Faraday in 1995 ($P=0.020$ and 0.005 respectively). *E. autumnalis* bulbs bought from Faraday in 1995 and present in Faraday in 2001 were significantly smaller than the bulbs in the shops in 1995 ($P=0.0006$ and 0.0307 respectively) (Fig. 4). However, *E. autumnalis* bulbs sold in Faraday in 1995 were not significantly smaller than the bulb sizes present in Faraday in 2001 ($P=0.64$). While the mean bulb diameters of *M. plumbea* declined very slightly between 1995 and 2001, the differences in the means were not significant for any of the samples.

While there appeared to have been a decrease in the prevalence of larger bulbs (as indicated by the mean and modal diameters) between S 1995 and F 2001, these differences were only significant for *E. autumnalis*. Additionally, mean diameters for three of the four bulb species showed that bulbs bought from Faraday in 1995 were smaller than bulbs sold in the shops in 1995 and even in Faraday in 2001 (Fig. 4). One explanation for

Table 2
Differences in the mean (±SD) mass of the individual bulbs/corms sold in the shops and Faraday in 1995

Species	Mean individual bulb mass ±SD (kg)		t-value	df	P
	Shops 1995	Faraday 1995			
Drimia spp.	0.335±0.170	0.092±0.157	6.22	74	<0.000001
Eucomis autumnalis	0.284±0.204	0.096±0.100	5.39	74	0.000001
Merwilla plumbea	0.490±0.316	0.394±0.247	0.99	36	0.330
Hypoxis spp.	0.254±0.204	0.148±0.160	2.26	59	0.028

Table 3
Mean (±SD) length, number of individual plants per bundle and mass per bundle of the woody rootstocks sold in the traditional medicine shops in 1995

Species	Mean root length (cm)	Mean no. plants/bundle	Mean mass/bundle (kg)
	±SD	±SD	±SD
Scabiosa columbaria	6.9±1.8	25.3±8.3	0.066±0.083
Dianthus mooiensis	7.6±1.9	25.1±10.1	0.065±0.028

No equivalent data were collected for plants sold in the Faraday market in 2001.

Table 4
Estimated quantities of bulbs purchased per annum by the Johannesburg traditional medicine shops in 1995 and the Faraday market traders in 2001

	Drimia spp.	*Eucomis autumnalis*	*Merwilla plumbea*	*Hypoxis* spp.
Muti shops 1995				
% traders sold species (n=50)	78	78	76	62
Est. no. bags purchased by 189 traders in 1995 (bags a^{-1})	1961	1695	1350	445
Modal diameters present (cm)	7	8	7	6
Est. no. of IE bulbs a^{-1}	386 513	233 910	266 085	125 268
Faraday 2001				
% traders sold species (n=100)	60	21	25	39
Est. no. bags purchased by 164 traders in 2001 (bags a^{-1})	443	121	135	422
Modal diameters present (cm)	6	4	6	5
Est. no. of IE bulbs a^{-1}	124 705	69 490	38 003	169 686

The number of individual equivalent (IE) bulbs was determined from the number of bulbs per bag for the modal diameters present in the markets.

this result concerns the time when the F 1995 survey was conducted, namely in the winter months between July and September. Traders usually can't purchase new stock during winter because of bulb dormancy and they sell plants harvested in the previous growing season. If larger bulbs are preferred by customers and sold first, then proportionally more small bulbs remain — and it was from this stock that bulbs were sampled.

The increased prevalence of smaller bulbs in Faraday during the winter of 1995 is supported by evidence of a decrease in the mean mass of the individual bulbs (Table 2). However, no equivalent data on bulb masses were collected for bulbs sold by the traders in Faraday in 2001. Similarly, no size data were recorded for the woody rootstocks of *S. columbaria* and *D. mooiensis* in 2001. In 1995, however, there were ≈ 25 individual plants per bundle, with each bundle weighing around 66 g (Table 3).

3.3. Estimated quantities purchased annually

The number of 50-kg bags of bulbs estimated to have been purchased between 189 shops in the Witwatersrand in 1995 was highest for *Drimia* spp. (1961 bags a^{-1}) and lowest for *Hypoxis* spp. (445 bags a^{-1}) (Table 4). *Hypoxis* spp. was also the least common of the four bulbs sold in the shops, with only 62% of the vendors selling the species. *Drimia* spp. was similarly estimated to be purchased in the largest quantities (compared to the other bulb species) between the 164 traders in Faraday in 2001 (443 bags a^{-1}), compared to only 121 bags a^{-1} for *E. autumnalis* (Table 4). *S. columbaria* and *D. mooiensis* were less prevalent than the bulb species, and were sold in smaller quantities in both the shops and Faraday (Table 5).

At face value, these results would *appear* to show there to have been a marked decrease in the quantities harvested annually and sold to the shops and Faraday traders between 1995 and 2001 (Table 4). However, the quantities are not practically comparable given contrasts in the type of trade conducted in the shops and Faraday, the clientele served, differences in the numbers of traders selling the species and, the temporal changes in species availability and demand. Furthermore, traders from shops had few storage constraints and a habit of stock-piling certain species, especially those that were scarce. Traders in Faraday, by contrast, were limited by capital and capacity to the quantity of plants they could buy and sell. While Faraday is the largest street market in the province, the traders there are not the only wholesalers of traditional medicine and they represent one component of the wholesale supply chain. More important to this study is the relative order of magnitude of the annual purchases when comparing species. Additionally, a focus of this paper was to describe a procedure for translating the *quantity* (i.e. bags a^{-1}) purchased, into the *number* of individuals harvested to identify the extent of resource depletion.

3.4. The number of Individual Equivalents

A relatively strong positive relationship existed between bulb diameter and the number of bulbs per 50-kg bag (r^2=0.818, P=0.017) (Fig. 5). This relationship was used to calculate the number of Individual Equivalent (IE) bulbs harvested annually from the number of 50-kg bags estimated to be purchased. The bulbs were equivalent in diameter to the individuals most prevalent in the markets in 1995 and 2001 (i.e. from the modal diameter).

Based on the modal diameters, estimates for the number of IE bulbs harvested and for sale in the Witwatersrand shops in 1995 ranged from 125 268 bulbs all ≈ 6 cm in diameter, to 368 513 bulbs that were ≈ 7 cm in diameter for *Hypoxis* spp. and *Drimia* spp. respectively (Table 4). By contrast, estimates for the number of bulbs sold to Faraday traders in 2001 ranged from 38 003 *M. plumbea* bulbs ≈ 6 cm in diameter, to 169 686 *Hypoxis* spp. bulbs ≈ 5 cm in diameter (Table 4).

The number of estimated IEs varied depending on the diameter class selected *and* the quantity traded. Fig. 6 presents additional scenarios for the number of bulbs bought by shops in 1995 and the Faraday traders in 2001. The calculations are for the same quantities (bags a^{-1}) listed in Table 4, but are adjusted depending on the diameter of the most prevalent size-classes.

Table 5
Estimated quantities of *Scabiosa columbaria* and *Dianthus mooiensis* purchased per annum by the Johannesburg traditional medicine shops in 1995 and the Faraday market traders in 2001

	Scabiosa columbaria	*Dianthus mooiensis*
Muti shops 1995		
% traders sold species (n=50)	58%	60%
Estimated no. bags* purchased by 189 traders in 1995 (bags a^{-1})	208	306
Est. no. of individual plants harvested	1 040 000	1 530 000
Faraday 2001		
% traders sold species (n=100)	6%	8%
Estimated no. bags* purchased by 164 traders in 1995 (bags a^{-1})	26	45
Est. no. of individual plants harvested	130 000	225 000

*Bag = volume equivalent to a 50-kg size bag.

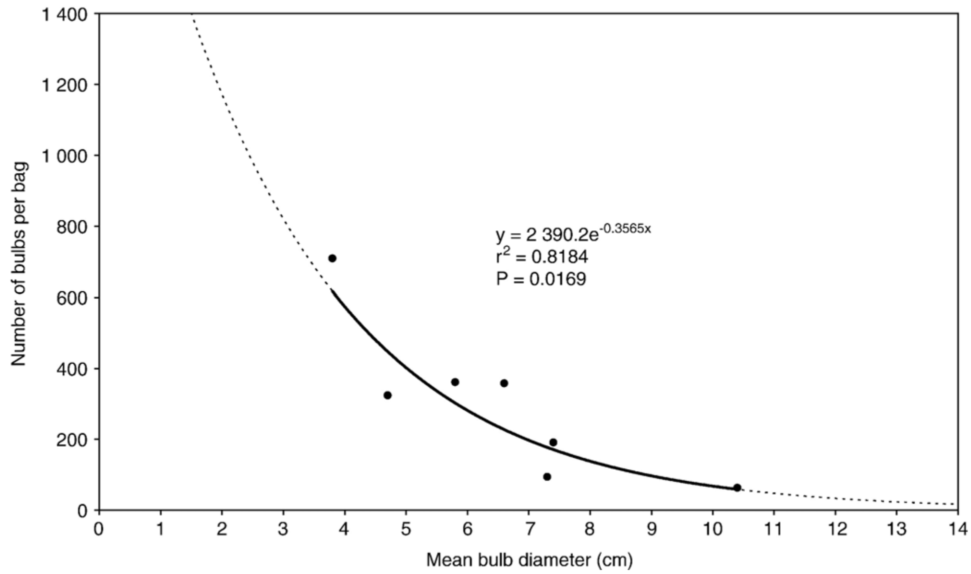

Fig. 5. The regression relationship for the number of bulbs contained in a 50-kg size bag depending on the bulb size [Graph derived from raw data in Cunningham (1988), Table 5, for seven species].

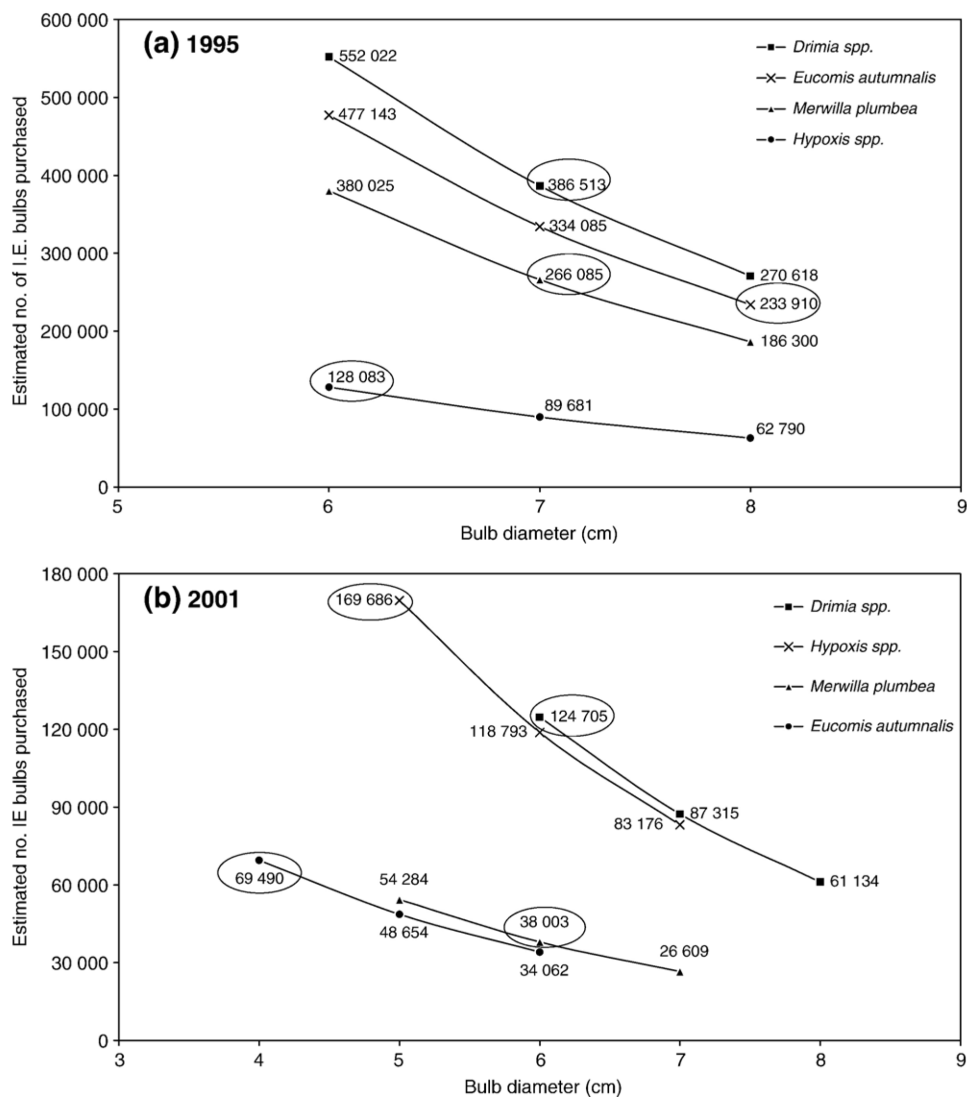

Fig. 6. Scenarios for the number of individual equivalents (IE) purchased by (a) the *muti* shops in 1995 and (b) the Faraday market in 2001, depending on the three most prevalent diameter classes. Encircled estimates represent the modal diameters recorded.

The estimates encircled in Fig. 6 are those listed in Table 4; however, the graphs illustrate how the order of magnitude of the number of individual bulbs harvested changes depending on the bulb diameter selected.

By selecting a particular bulb diameter on which to make the IE estimates, one is assuming (by this method) that *all* of the bulbs estimated to be harvested are this size. Hence, the smaller the bulb sizes selected, the more IE bulbs will be estimated from the quantity traded annually. However, bulbs are obviously not all from one diameter class and so the actual number of bulbs harvested annually will vary from the IE estimates depending on the preponderance and range of size-classes in the markets. Despite this caveat, the IE estimate provides a starting point for quantifying the annual extent of resource depletion.

The size of the whole plants of *S. columbaria* and *D. mooiensis* was not a critical factor in estimating the number of Individual Equivalents. The mean number of individual plants per bundle of these species was ≈ 25 and the number of bundles per 50-kg bag was 200 (Cunningham, 1988). Thus estimates for the number of individual plants sold to the shops in 1995 ranged from 1.04 to 1.53 million for *S. columbaria* and *D. mooiensis* respectively, and to traders in Faraday from 130 000 to 225 000 individuals (Table 5).

4. Discussion

Size-class distributions allow for the identification of poorly-represented life history stages (Hall and Bawa 1993). By recording and reconstructing information on species size-class selection from market surveys, an opportunity is presented to assess the impact of harvesting on plant populations (Cunningham, 2001). Assuming that bulb diameter is positively correlated with plant age and fitness, then life history stages that may be affected by harvesting may become apparent when reconstructing the frequency of bulb diameter distributions. Furthermore, the prevalence of certain size-classes may be representative of what is available in the wild or what is preferentially targeted by harvesters.

In South Africa, research has been conducted on germination rates and seedling establishment for some important bulb species (e.g. Kulkarni et al., 2005; Sparg et al., 2005). However, there are few studies that record assessments of harvesting impacts based on size-class selection *and* population age structures for medicinal plants [except, for example, some tree species (Botha et al., 2002, 2004), species used by communities in Lesotho (Letsela, 2004) and *M. plumbea* (Williams et al., 2006)]. This makes it difficult to construct models that predict the rate of population decline should deterministic factors that currently endanger plant populations persist. There is evidence that plant size is correlated with plant fitness, and an inordinately large proportion of the genes of a plant population may be descended from a very small number of individuals from a previous generation (Weiner and Solbrig, 1984). Thus, the removal of large, reproductive individuals from a population has a detrimental impact on the fitness of a plant population, especially since larger individuals tend to produce larger quantities of seed (Cunningham, 2001). To optimise harvesting efficiency and income, however, gatherers generally select plants from dense stands as well as the largest individuals from within the population (Cunningham, 2001). The size and proportion of the bulbs harvested therefore has important implications for plant recruitment and the perpetuation of species in a community.

Most of the bulbs sold by the traders were within the size ranges and limits recorded by other authors as typical for the species in the wild. *Drimia elata* bulbs typically range from 4 to 10 cm in the wild (Pooley, 1998), and 82% of the bulbs recorded in the markets were 4–10 cm (Fig. 3a). Only 5% of the measured *Drimia* bulbs were >10 cm. The mean diameter of *Drimia* spp. decreased between 1995 and 2001 (8.1 ± 1.6 cm to 6.8 ± 2.4 cm respectively) (mean ± SD), but the differences were not significant (Fig. 4a).

E. autumnalis are reported to grow to 10 cm in diameter (Pooley, 1998; Crouch et al., 2005), but are often 5–10 cm (Mander et al., 1995). No *E. autumnalis* bulbs > 10 cm were measured in the markets (Fig. 3b), but overall only 51% were 5–10 cm. There was a significant decrease in the mean diameter of the bulbs present in the shops in 1995 compared to Faraday in 2001 (6.8 ± 2.2 cm and 5.2 ± 2.2 cm respectively) (Fig. 4b), thus indicating that harvesting for the trade has probably had a significant negative impact on the resource base. In Mpumalanga in 1997, Botha et al. (2001) recorded *E. autumnalis* bulbs to be 7.5 ± 0.5 cm (mean ± SE) in diameter. However, no bulbs <7 cm were recorded during her survey — possibly indicating that larger bulbs were still quite accessible to harvesters at the time.

Another noteworthy result from the 1997 Mpumalanga study (Botha et al., 2001) was that the diameter range of *Hypoxis* spp. was 9–12 cm (mean ± SE = 10.6 ± 0.6 cm), which is higher than the average diameter range recorded for the genus in the Witwatersrand (Figs. 3d and 4d). Crouch et al. (2005) reported *H. hemerocallidea* corms growing to diameters of 2.5–7 cm, but they can also get as big as 10 cm (Hawker et al., 1999). Only 1% of the *Hypoxis* spp. corms recorded in the Witwatersrand markets were > 10 cm diameter and 77% were 2–7 cm (Fig. 3d). The ANOVA indicated no significant change in the mean corm diameters between 1995 and 2001 (6.7 ± 1.5 cm and 6.8 ± 2.0 cm respectively). These results, and those from the Mpumalanga study, therefore seem to indicate that large corms at the high end of the size-class range were still prevalent in the markets up to 2001.

M. plumbea is usually the largest of the bulb species in the markets. The mean mass of individuals in the shops in 1995 was 0.49 ± 0.32 kg (Table 2). The bulbs are generally known to grow to 10–20 cm in diameter, and even up to 30 cm (Mander et al., 1995; Pooley, 1998; Douwes et al., 2001; Crouch et al., 2005), however no individual bulbs >13 cm were recorded in the Witwatersrand markets (Fig. 3c). It is possible, however, that records of *M. plumbea* bulbs being > 15 cm are for bulb clusters rather than individuals. The mean diameter of the bulbs sold between 1995 and 2001 did not change significantly (7.4 ± 1.5 cm and 7.1 ± 2.7 cm respectively) (Fig. 4c), and the sizes are similar to those recorded in Mpumalanga in 1997 (Botha et al., 2001), namely 7.6 ± 0.6 cm (mean ± SE). Like *Hypoxis* spp., there were no obvious changes in the availability and prevalence of larger bulbs in the Witwatersrand markets up to 2001.

Over time, there is often a progressive decline in the bulb diameters of heavily exploited species (Cunningham, 2001), which can be mirrored in bulb diameter frequency distributions recorded in medicinal markets. Our results served to confirm: 1) that harvesters extracted bulbs from the known range of size-classes typical for the species; 2) that large bulbs at the upper end of the size-class range are known to have been present in the markets during surveys conducted between 1995 and 2001; and 3) that the absence and/or decline of large bulbs recorded in future surveys would indicate erosion of the resource base. There are no data to gauge the extent of this decline in the Witwatersrand markets prior to 1995, except for anecdotal evidence from the traders. However, there was a significant decrease in the mean size of *E. autumnalis* bulbs between 1995 and 2001 ($P = 0.031$). *Drimia* spp., while exhibiting no significant difference in mean diameter, also appeared to be declining in size ($P = 0.068$) (Fig. 4). Given the popularity of bulb species and the volumes reportedly harvested in KwaZulu-Natal, Mpumalanga and the Witwatersrand (Mander, 1998; Botha et al., 2001; Williams, 2003), a more significant negative shift in the prevalence of larger bulbs would be expected if markets were to be re-surveyed in future. An implication of the decline in availability of larger bulbs is that greater quantities of smaller bulbs have to be harvested to be equivalent to the volume usually sold. With the demand for bulbs not likely to decline in the near future, the pressure on existing plant populations and their fitness is significant.

Insight into market practises when resource becomes limited was gained from comparing the mean bulb diameters sold by traders in the shops and Faraday in 1995. The shop and Faraday surveys were conducted from April to October and July to September 1995 respectively. Bulb stocks in the markets are depleted during winter because of bulb dormancy and consequent reduced harvesting activities. Fresh bulbs typically start arriving from September. There appears to a tendency for the larger bulbs to be sold first, as evidenced from the significant differences in the mean bulb diameters measured for *Drimia* spp., *E. autumnalis* and *Hypoxis* spp. in the shops and Faraday (Fig. 4). Smaller bulbs were more prevalent in Faraday because the larger individuals had been sold earlier on. And, while the sizes of the *individual* bulbs sold at Faraday were smaller, the actual mass of a sale of a quantity of bulbs was significantly greater — especially for *E. autumnalis* and *Hypoxis* spp. (Williams, n.d.). Traders therefore compensate for the lack of bigger bulbs by selling more smaller ones that equate to approximately the same volume per sale to a customer.

The regression analyses between bulb diameter and mass generally show a strong positive relationship (Fig. 2), especially for species like *Drimia* spp. that tend to remain fleshy and do not have papery, flaky outer bulb scales like *E. autumnalis* and *M. plumbea* do. As bulbs age, the number of leaf scales increases and the bulbs increase in diameter and mass. For species where the most peripheral bulb scales become dry and flaky, there is greater variability in bulb mass with increased diameter.

Precise measures of the quantities sold are not possible but recognition of the order of magnitude is necessary if resource management alternatives are to be seen in perspective (Cunningham, 1988). Results indicated that *Drimia* spp. is the most heavily traded bulb on the Witwatersrand (Table 4). In 1995, *E. autumnalis* was also purchased in large quantities, but the magnitude of purchases (bags a^{-1}) relative to other species had dropped by 2001, possibly because of declining availability due to dwindling wild stocks. The market share of *Hypoxis* spp. appeared to have increased — perhaps because of the publicity it received after a series of media releases in 1997 that proclaimed its healing properties (Drewes and Horn, 1999). In 1995, some shop traders considered *Hypoxis* a "useless line" and bought less than 1 bag a^{-1} to meet demands. A result of the publicity was the proliferation of "*illicit phytomedicines of questionable quality*" that depended on wild harvesting to supply the market (Hawker et al., 1999), hence increasing its market profile and the quantities harvested.

The large differences in the quantities estimated to be purchased by traders in 1995 and 2001 does not imply that the amount harvested and the demand had dropped (Table 4). However, the intra-species quantity differences put species management into perspective and inform the relative urgency of conservation measures. The shops and Faraday represent different sectors of the market chain, hence the annual throughput will differ in each sector. Furthermore, traders in Faraday are not the only wholesale suppliers of medicinal plants in the region. In 1995, Faraday probably supplied 31% of the stock to shops (Williams et al., 2000). In 2006, one shop trader estimated that <40% of the bulbs he bought were from Faraday (C. Dorasamy, pers. comm.), the remainder being purchased from harvesters that went directly to the shop. A speculative question worth considering, is whether the annual volumes sold through Faraday account for ≤40% of the Witwatersrand trade?

The response of plants to exploitation and the implications of declining productivity under high frequency or intensity of exploitation are critical to policy development for particular species (Cunningham, 1988). To be able to estimate the number of individuals harvested annually is therefore an invaluable tool for resource managers. Conservation efforts could subsequently be directed at high priority species where many individuals are damaged or removed by gatherers of medicinal plants. Ideally, knowledge of how many plants are harvested annually would be used in conjunction with demographic data for the species so that the impact of harvesting can be more thoroughly assessed.

Mander (1998) estimated that 73.2 tonnes and 95.5 tonnes of *E. autumnalis* and *M. plumbea* respectively were traded per year in the Durban medicinal plant trade, equating to approximately 428 000 and 432 000 equivalent bulbs used per year respectively. Comparable figures for equivalently smaller bulbs (≈ 6 cm) were estimated for both these species in the Witwatersrand shops in 1995 (Fig. 6a). It was also estimated that shops in 1995 bought ≈ 1961 bags of *Drimia* spp. Assuming that all the individual bulbs were equivalent in size to the modal diameter of 7 cm, then the number of Individual Equivalent bulbs estimated to be bought in 1995 was 386 513 (Table 4, Fig. 6a). The scenarios for the number of Individual Equivalent bulbs in 2001 bought by traders in Faraday are less (Fig. 6b), but Faraday represents one sector of the medicinal plant trade in the region. And, as the prevalence of larger bulbs declines in the markets, so the number of smaller bulbs harvested increases and the scenarios for the number of bulbs traded annually changes (Fig. 6).

In conclusion, the intention was to demonstrate how bulb size records collected during market surveys can be used to assess the extent of resource exploitation and the condition of the resource in the wild. The approach presented moves away from discussing harvesting impacts in terms of the mass sold, and uses instead the prevalence of bulb diameter size-classes as a surrogate for estimating what size of bulbs might be present in wild populations and the number that are potentially removed by harvesters. The magnitude of the trade and the number of plants harvested subsequently informs species specific conservation action that needs to be taken. From the results, it was evident that the size of *E. autumnalis* bulbs in the markets decreased significantly between 1995 and 2001, that *Drimia* spp. is the species most in demand in the region and, that the number of individual bulbs harvested annually is very high. These species warrant practical conservation action to mitigate the effects of further unsustainable exploitation for both the Witwatersrand markets and the rest of the country.

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References

Begon, M., Harper, J.L., Townsend, C.R., 1986. Ecology: Individuals, Populations and Communities. Blackwell Scientific Publications, USA.

Botha, J., Witkowski, E.T.F., Shackleton, C.M., 2001. An inventory of plants traded on the Western Boundary of the Kruger National Park, South Africa. Koedoe 44, 7–46.

Botha, J., Witkowski, E.T.F., Shackleton, C.M., 2002. A comparison of anthropogenic and elephant disturbance on *Acacia xanthophloea* (fever tree) populations in the Lowveld, South Africa. Koedoe 45, 9–18.

Botha, J., Witkowski, E.T.F., Shackleton, C.M., 2004. The impact of commercial harvesting on *Warburgia salutaris* ('pepper-bark tree') in Mpumalanga, South Africa. Biodiversity and Conservation 13, 1675–1698.

Crouch, N., Symmonds, R., Spring, W., Diederichs, N., 2005. Fact sheet for growing popular medicinal plant species. In: Diederichs, N. (Ed.), Commercialising Medicinal Plants: A Southern African Guide. Sun Press, Stellenbosch, South Africa, pp. 99–142.

Cunningham, A.B., 1988. An investigation of the herbal medicine trade in Natal/KwaZulu. Investigational Report, vol. 29. Institute of Natural Resources, Pietermaritzburg, South Africa.

Cunningham, A.B., 2001. Applied Ethnobotany: People, Wild Plant Use and Conservation. People and Plants Conservation Series. Earthscan Publications, London.

Douwes, E., Crouch, N.R., Symmonds, R., 2001. Blue squill in the red: *Scilla natalensis* as a conservation charge. PlantLife 24, 14–19.

Drewes, S., Horn, M., 1999. The African Potato *Hypoxis hemerocallidea* (Hypoxidaceae). Myth or miracle muthi. PlantLife 20, 29–31.

Geldenhuys, C.J., 2004. Meeting the demand for *Ocotea bullata* bark. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M., Geach, B.G.S. (Eds.), Indigenous Forests and Woodlands in South Africa: Policy, People and Practice. University of KwaZulu-Natal Press, Pietermaritzburg, South Africa, pp. 517–550.

Hall, P., Bawa, K., 1993. Methods to assess the impact of extraction of non-timber tropical forest products on plant populations. Economic Botany 47 (3), 234–247.

Hawker, L.C., Lumley, M., Swartz, P., Buckas, E., Nichols, G., Crouch, N., Prentice, C.A., Singh, Y., 1999. Growing a hot potato. Notes on the cultivation and propagation of *Hypoxis hemerocallidea*. PlantLife 21, 34–36.

Kulkarni, M.G., Sparg, S.G., van Staden, J., 2005. Temperature and light requirements for seed germination and seedling growth of two medicinal Hyacinthaceae species. South African Journal of Botany 71, 349–353.

Letsela, T. 2004. Sustainable Utilisation of Communal Plant Resources within the Tsehlanyane-Bokong Biosphere Reserve in Lesotho. PhD Thesis, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa.

Mander, M., 1998. Marketing of indigenous medicinal plants in South Africa. A case study in KwaZulu–Natal. FAO Report, Rome.

Mander, M., Mander, J., Crouch, N., McKean, S., Nichols, G., 1995. Catchment Action: Growing and Knowing Muthi Plants. Share-Net, Howick, South Africa.

Pooley, E., 1998. A Field Guide to Wild Flowers KwaZulu–Natal and the Eastern Region. Natal Flora Publications Trust, Durban, South Africa.

Sparg, S.G., Kulkarni, M.G., van Staden, J., 2005. Germination and seedling establishment strategies for *Merwilla natalensis*, a South African medicinal plant in high demand. South African Journal of Science 101, 205–208.

Twine, W., 2004. Medicinal bark harvesting and yields in woodlands: a case study from southern Maputaland. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M., Geach, B.G.S. (Eds.), Indigenous Forests and Woodlands in South Africa: Policy, People and Practice. University of KwaZulu-Natal Press, Pietermaritzburg, South Africa, pp. 533–537.

Van Wyk, B., Malan, S., 1988. Field Guide to the Wild Flowers of the Witwatersrand and Pretoria Region. Struik, Cape Town, South Africa.

Von Ahlefelt, D., Crouch, N.R., Nichols, G., Symmonds, R., McKean, S., Sibiya, H., Cele, M.P., 2003. Medicinal Plants Traded in South Africa's Eastern Seaboard. Porcupine Press, Durban, South Africa.

Weiner, J., Solbrig, O.T., 1984. The meaning and measurement of size hierarchies in plant populations. Oecologia 61, 334–336.

Williams, V.L., 2003. Hawkers of Health: an Investigation of the Faraday Street Traditional Medicine Market in Johannesburg, Gauteng. Report to Gauteng Directorate of Nature Conservation, DACEL. Plant Ecology and Conservation Series, vol. 15. University of the Witwatersrand, South Africa.

Williams, V.L., 2004. Trade and socio-economic value of forest and woodland resources within the medicinal plant market in Johannesburg. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M., Geach, B.G.S. (Eds.), Indigenous Forests and Woodlands in South Africa: Policy, People and Practice. University of KwaZulu-Natal Press, Pietermaritzburg, South Africa, pp. 439–472.

Williams, V.L. (n.d.) The design of a risk assessment model to determine the impact of the herbal medicine trade on the Witwatersrand on resources of indigenous plant species. PhD Thesis, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa Unpublished.

Williams, V.L., Balkwill, K., Witkowski, E.T.F., 2000. Unravelling the commercial market for medicinal plants and plant parts on the Witwatersrand, South Africa. Economic Botany 54, 310–327.

Williams, V.L., Raimondo, T., Cunningham, A.B., 2006. Trade, bulb age and impacts on *Merwilla plumbea* (Hyacinthaceae). Report to People and Plants International, IDRC. Unpublished.

Williams, V.L., Witkowski, E.T.F., Balkwill, K., in press. Assessing harvesting impacts for species used medicinally in South Africa: estimates of the number of individual trees debarked annually. Advances in Economic Botany.

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